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Enhanced performance of large 3ω optics using UV and IR lasers

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ABSTRACT

We have developed techniques using small-beam raster scanning to laser-condition fused silica optics to increase their damage threshold. Further, we showed that CO_2 lasers could be used to mitigate and stabilize damage sites while still on the order of a few tens of microns in size, thereby greatly increasing the lifetime of an optic. We recently activated the Phoenix pre-production facility to condition and mitigate optics as large as 43 cm x 43 cm. Several full-scale optics have been processed in Phoenix. The optics were first photographed using a damage mapping system to identify scratches, digs, or other potential sites for initiation of laser damage. We then condition the optic, raster scanning with the excimer laser. The first scan is performed at a low fluence. A damage map is then acquired and any new damage sites or any sites that have grown in size are mitigated using the CO_2 laser. The process is repeated at successively higher fluences until a factor of 1.7 above the nominal operating fluence is reached. After conditioning, optics were tested in a large beam 3ω laser and showed no damage at fluences of 8 J/cm^2 average.

1. INTRODUCTION

The output fluences that can be attained on the National Ignition Facility (NIF) and other mega-Joule class solid-state lasers are ultimately limited by laser-induced damage to optical components within the chain. When damage reaches performance-limiting levels, optics must be replaced leading to increased operating expense and laser down time. Laser damage thresholds decrease with decreasing laser wavelength, with the result that the final optics, operating at the Nd:glass harmonic wavelengths of 527 and 351 nm, are the most susceptible to damage. The final optics on the NIF consist of frequency doubling and tripling crystals fabricated from KDP and deuterated KDP, and a final focusing lens, beam sampling grating and main debris shield fabricated from fused silica.

Over the last several years we have developed techniques using small-beam raster scanning to laser-condition fused silica optics to increase their damage threshold. [1] Further, we showed that CO_2 lasers could be used to mitigate and stabilize damage sites while still on the order of a few tens of microns in size, thereby greatly increasing the lifetime of an optic through reuse. [2] With construction of the NIF proceeding, the ability to process full-scale 43 cm x 43 cm optics is required.

2. CONDITIONING AND MITIGATION PROCESS

The conditioning and mitigation process involves an off-line facility where a laser is raster scanned across the optics starting at low fluences; repeating in steps at increasing fluences. Before and after each conditioning step the optic is photographed to record any changes in damage condition. After each scan, any changed or new surface sites are mitigated using a CO_2 laser.

The optics were first photographed using a damage mapping system to identify scratches, digs, or other potential sites for initiation of laser damage. The damage mapping system consists of halogen side lights to illuminate the optic and a 8000 x 1 pixel linear scanning CCD camera that provides a defect detection capability of ≈20 µm. Figure 1 shows a typical map of an optic prior to conditioning.

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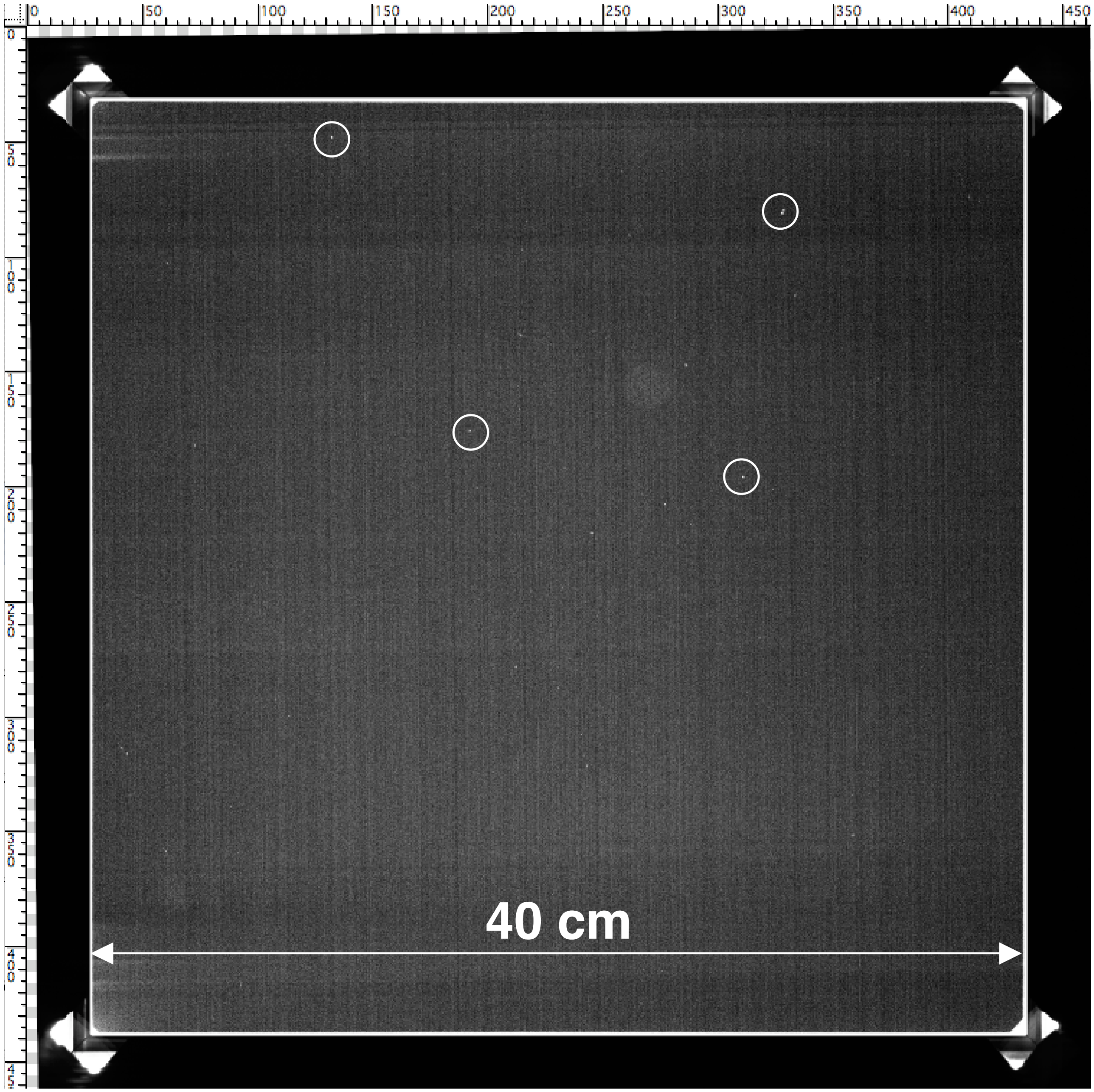

Figure 1: Image of full-size optic showing some of the initial defects circled.

The conditioning laser (a UV laser at ≈350 nm) is then used to raster scan the optic at increasing fluences. This process is repeated in steps to a maximum of 1.7 times the average operating fluence to initiate all sites on the surface that would initiate in many shots of normal system operation. The optic is imaged after each raster scan. Any site that scatters more light after the scan than before is investigated further with a long working distance microscope. Figure 2 shows an enlarged area of the image shown in Figure 1 and the same area after a raster scan showing two sites (encircled) that changed after the scan. If the site is identified as surface damage it is mitigated.

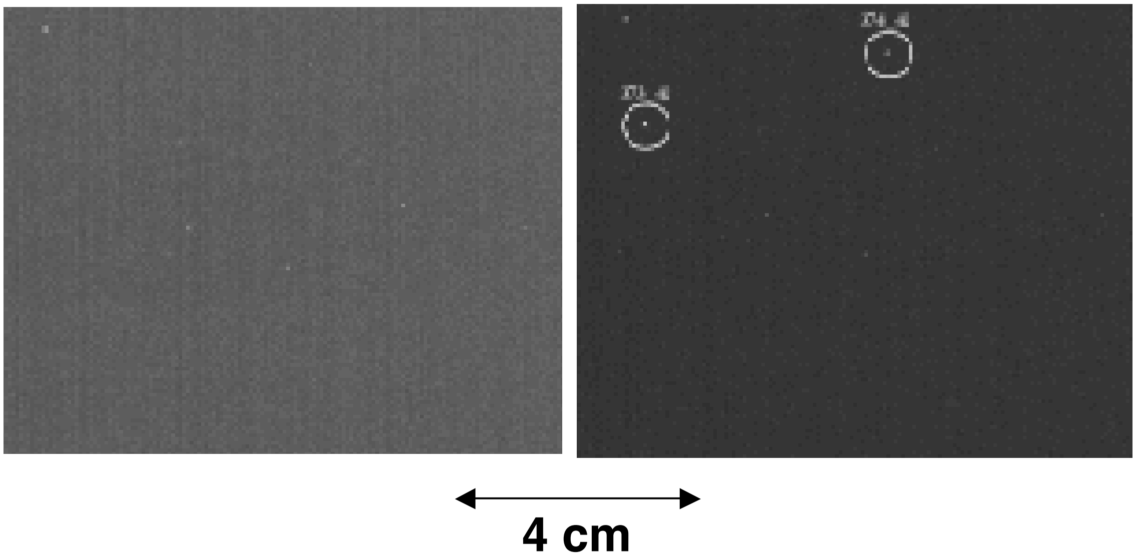

Figure 2: Enlarged section of the image of the optic shown in Figure 1 on the left. The same region after a raster scan is shown on the right with two sites that have changed encircled.

The third step in the process is to mitigate observed surface defects to reduce their probability of damage. Any new damage sites or any sites that have grown in size are mitigated using the CO_2 laser. Figure 3 shows an example of damage sites that have been successfully mitigated. It shows a pair of small ≈100 µm diameter sites and a pair of scratches that were about 100 µm wide and about 1 mm and 3 mm long, that were successfully mitigated with a series of 50 ms pulses from a 50 W Gaussian beam CW CO_2 laser. After conditioning, optics were tested in a large beam 3ω laser and showed no damage at fluences of 8 J/cm^2 average.

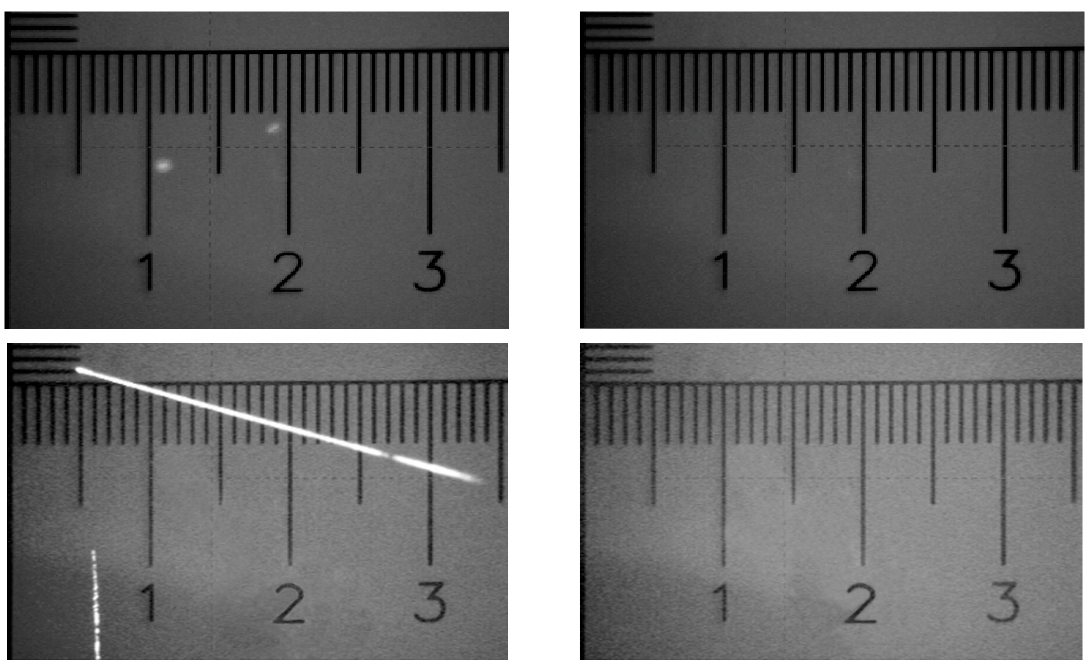

Figure 3: Example of mitigation using a CO_2 laser. The photographs on the left shows the sites before mitigation, while the photographs on the right the same sites after mitigation. The scale reads in mm.

3. PHOENIX PRE-PRODUCTION FACILITY

We have recently activated the Phoenix pre-production facility (shown in Figure 4) to condition and mitigate optics as large as 43 cm x 43 cm. The facility is equipped with two UV conditioning lasers – a 355-nm Nd:YAG laser operating at 50 Hz with a pulse width of 3.7 ns, and a 351-nm XeF excimer laser operating at 100 Hz and 23 ns. The facility also includes a CO_2 laser for damage mitigation, an optics stage for raster scanning full-scale optics, a damage mapping system (DMS) that images full-scale optics and can detect damage sites or precursors as small as ≈20 μm, and two microscopes to image damage sites with ≈5 μm resolution. The optics are handled in a class 100 clean room within the facility that is maintained at class 1000. This facility has been used to refine the conditioning protocol used for fused silica optics and the mitigation technique to reduce growth of damage. It has also been used to tailor the mitigation process to produce mitigated sites that have minimal downstream modulation. Several full-scale optics have been processed in the Phoenix laboratory.

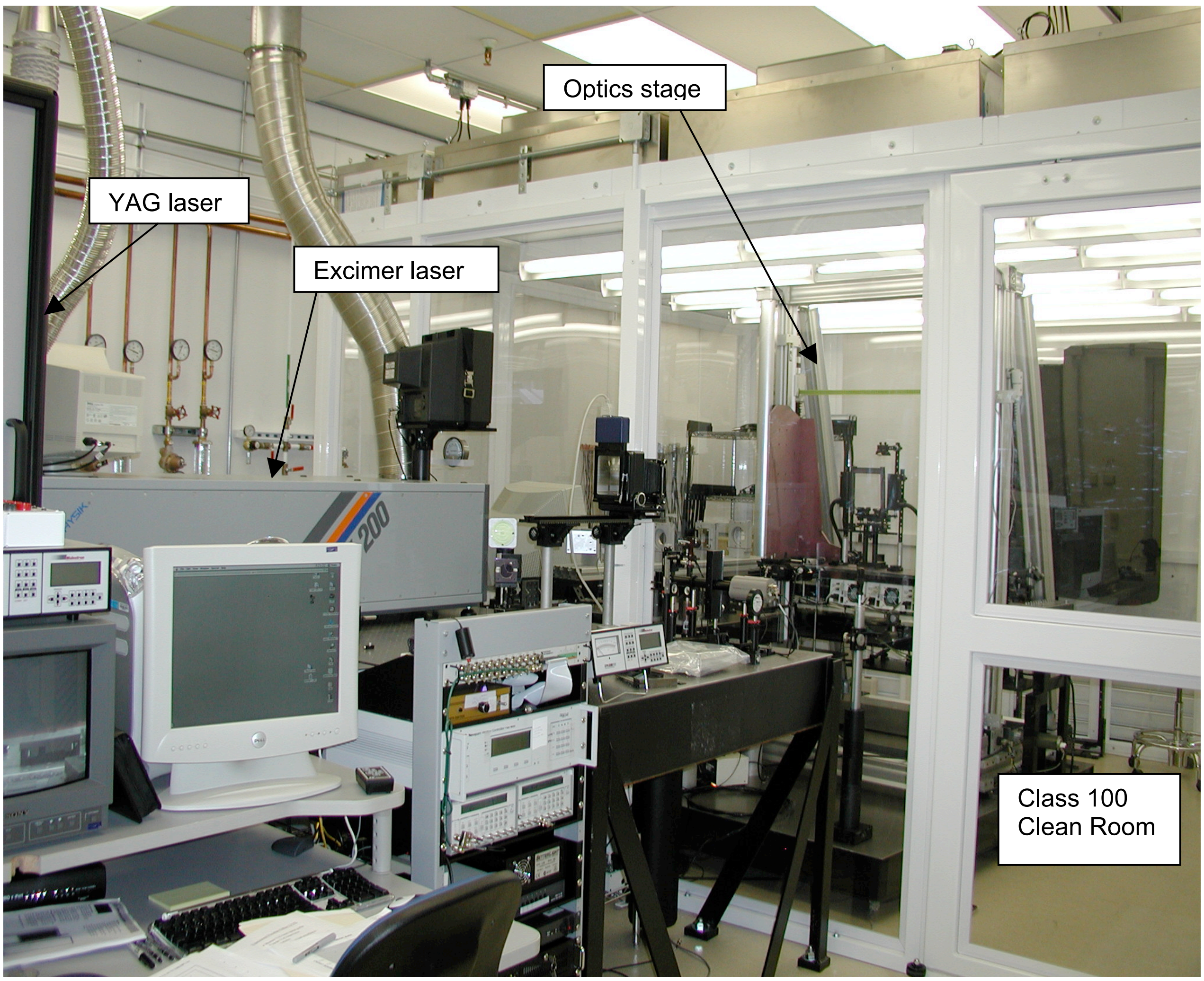

Figure 4: Phoenix facility

Two types of conditioning lasers have been used in our prototype system – an excimer laser and a YAG laser. The excimer laser is a 351 nm XeF system that operates at 100 Hz producing 280 mJ/pulse. The temporal pulse width of the laser pulses is 23 ns. This must be compared to the 3 ns pulse width of the YAG system that operates at 50 Hz, producing 200 mJ/pulse. The effective conditioning fluence scales as the square root of the pulse width, thus the YAG laser enjoys a factor of 2.9 advantage in terms of effective conditioning fluence. However, this advantage is offset by the fact that the excimer laser produces a rectangular top-hat spatial profile laser beam when configured with the appropriate beam delivery system, but the YAG laser produces the more inefficient round top-hat beam. [3] In addition, the excimer systems are commercial off-the-shelf products while the YAG systems are commercial systems that must be customized for this application.

The conditioning laser used for the pre-production activities in Phoenix was the excimer laser. The Phoenix XeF excimer laser operates at 280 mJ/pulse and uses an one-dimensional beam homogenizer to tailor the beam profile delivered to the optic. This homogenizer converts the 24 mm x 12 mm beam from the laser into a 1.5 mm by 0.3 mm focal spot. The intensity profile at the focus is a top hat along the long axis with a <3% rms deviation and a Gaussian along the short axis. The beam profile at the image plane of the homogenizer is shown in Figure 5. The spatial profile as a function of distance near the beam focus was measured. Figure 6 shows the full width at half maximum of the beam as a function of distance from the image plane in both long and short axes. Due to the relatively small f-number of the optical system (f/13), the positioning of the optical surface being conditioned is critical.

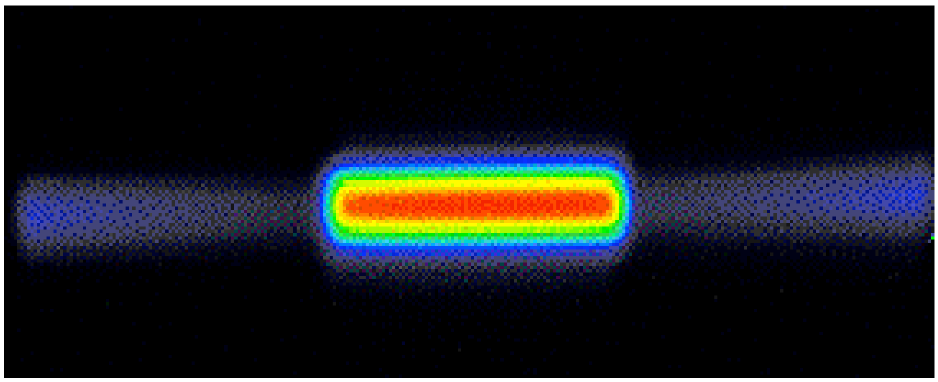

Figure 5: Beam profile of the excimer laser beam at the image plane of the beam homogenizer.

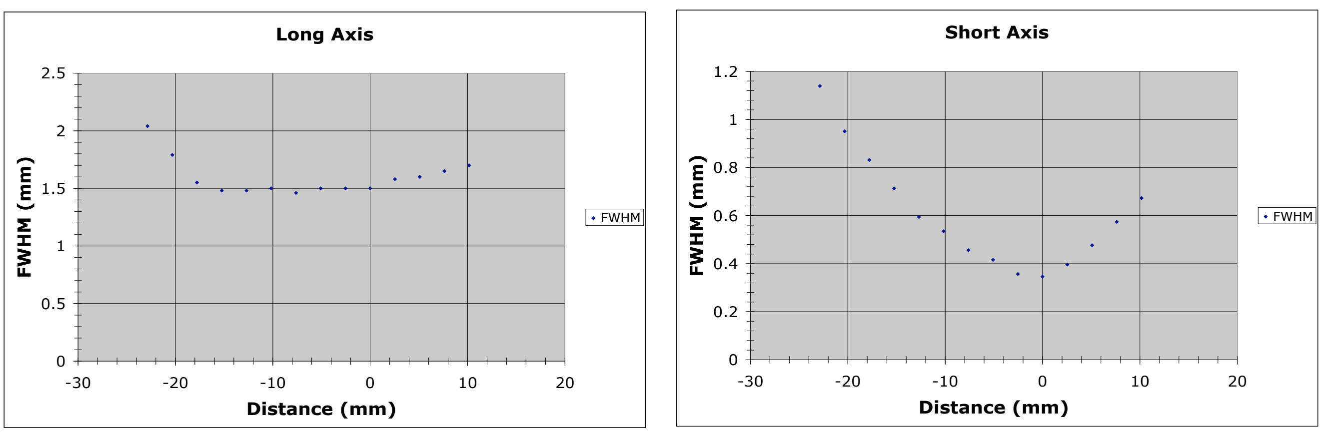

Figure 6: Full width at half maximum as a function of distance of the excimer beam.

The excimer beam cannot be focused at both front and rear surfaces of the optic simultaneously. We thus condition the output surface first, then move the optic and condition the input surface. The situation is further complicated in the case of curved surfaces as in the case of lenses. In this case uniform fluence is achieved by translating the optic along the direction of the excimer beam. Subsequently measurements of the beam size were made at nine locations as shown in Figure 7. The maximum peak to valley fluence variation observed along the curved surface was only 8.5%.

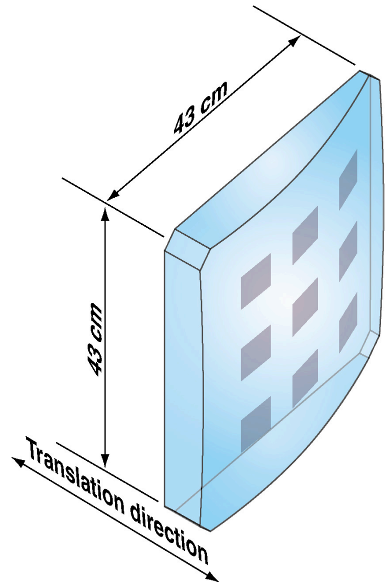

Figure 7: Sketch showing the measurement locations to determine the fluence uniformity on a curved optic.

4. CONCLUSION

We have processed several NIF optics in the Phoenix facility. Figure 8 shows the defect density as a function of fluence. Test optics that were tested during the prototyping phase in Phoenix yielded the upper curve shown as conventional finishing in the graph. While we refined the conditioning and mitigation process our optics vendors have been improving their finishing processes. It is the result of the new finishing processes that produces optics with very few (0-5) defects in a full size optic. Recent advances in finishing processes used to fabricate NIF fused silica optics and the development of conditioning and mitigation results in a process that is feasible for large (43 cm x 43 cm) optics.

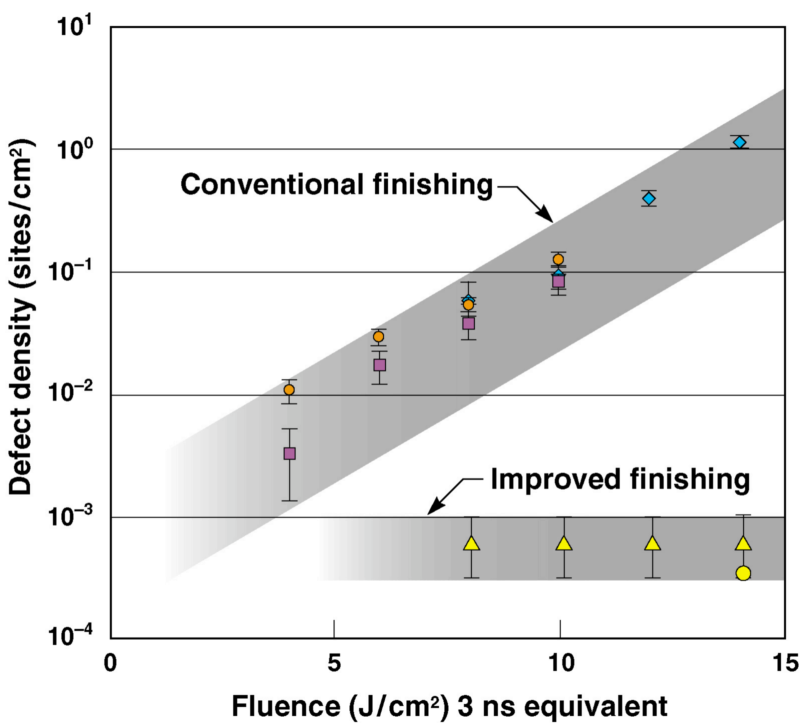

Figure 8: Defect density of optics.

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